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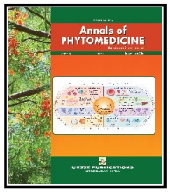

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From fragrance to pharmacology: Unlocking the therapeutic potential of *Jasminum sambac* (L.) Aiton

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Abstract

Jasminum sambac (L.) Aiton, is widely recognized not only for its fragrance and ornamental value but also for its long-standing use in traditional and folk medicine across many Asian cultures. Different plant parts have historically been used to manage conditions such as inflammation, infections, fever, and skin disorders. Scientific investigations have revealed a rich repertoire of bioactive phytochemicals, including flavonoids, phenolics, terpenoids, sterols, and peptide compounds distributed across various plant parts. These constituents are associated with diverse pharmacological activities, including antioxidant, antiinflammatory, antimicrobial, antidiabetic, anticancer, and neuroprotective effects demonstrated through *in vitro* and *in vivo* experimental models. The pharmacological potential of plant extracts and isolated compounds highlights the therapeutic relevance of this species. Overall, *J. sambac* represents a promising natural source for the development of pharmaceutical and cosmeceutical agents, although further clinical validation is necessary to support its therapeutic applications.

1. Introduction

Jasmine (*Jasminum* spp., family Oleaceae) is an economically and culturally important aromatic flowering plant cultivated widely in tropical and subtropical regions. The name jasmine originates from the Arabic word yasmin, meaning 'gift from God'. Being the largest genus within the family Oleaceae, *Jasminum* comprises of over 200 species distributed across tropical and subtropical regions worldwide.

The genus *Jasminum* is believed to have originated in the Himalayan region and the Indo-Malayan biodiversity belt, encompassing North Eastern India, Myanmar, Southern China, and Thailand (Priyadharshi *et al.,* 2025). From these centres of origin, jasmine species diversified throughout tropical Asia and subsequently spread to the Mediterranean and African regions through trade and cultivation. In India, approximately 40 species of *Jasminum* have been recorded, of which nearly 20 are cultivated, predominantly in southern regions (Bhattacharjee, 1980; Green and Miller, 2009). However, commercial cultivation in India is largely restricted to three species, namely: *J. sambac*, *J. grandiflorum*, and *J. auriculatum*. In recent years, under-exploited species such as *J. nitidum* and *J. multiflorum* have attracted attention due to their favourable horticultural traits, including off-season flowering and improved resistance to biotic stresses, indicating potential for expanded commercial utilization (Nair and Singh, 2000; Ganga *et al*., 2015; Nithisha *et al*., 2025).

Globally Egypt, India, and China are the major producers of jasmine, with Egypt dominating the international market by contributing approximately 50-70% of global production. The global jasmine oil market is expanding at an annual growth rate of 7.1%, driven by increasing demand from the perfumery, cosmetic, and aromatherapy industries. In India, jasmine represents a high value commercial flower crop with strong domestic and export demand. Commercial types such as *J. sambac* are extensively cultivated in districts including Madurai, Dindigul and Salem, with some cultivars registered under Geographical Indication (GI) tags. The area under jasmine cultivation increased from approximately 8,500 ha in 2013-14 to over 15,000 ha in 2023-24, accompanied by increased productivity resulting from improved cultivars and modern production technologies. Tamil Nadu leads national production, contributing about 180 thousand tonnes during 2023-24 (Priyadharshi *et al.,* 2025).

Among the wide range of species, *J. sambac* native to South Western and Southern Asia, (including the Philippines, India, Myanmar and Sri Lanka) is extensively cultivated for its ornamental value, intense fragrance, cultural and religious significance (Sanchez *et al*., 2010). Beyond its aesthetic appeal, *J. sambac* has attracted increasing scientific interest due to its rich phytochemical composition. Studies have identified essential oils, flavonoids, saponins and other bioactive compounds that contribute to its therapeutical properties, providing a biochemical basis for its traditional and emerging pharmaceutical applications (Gondkar *et al.,* 2024; Rescigno *et al*., 2025). This review

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aims to provide a comprehensive understanding of the ethnobotanical significance and therapeutic potential of *J. sambac* in both folk and modern medicine by integrating experimental evidences that link its phytochemical diversity to biological effects, while highlighting its potential applications in drug discovery and development.

2. Taxonomy of the plant

Among the cultivated jasmine species, *Jasminum sambac* (L.) Aiton, commonly known as Arabian jasmine, is a diploid ornamental species with somatic chromosome number of 2n = 2x = 26, while polyploids (2n=3x=39) are also prevalent. It is predominantly maintained through vegetative propagation and is valued for its white, highly fragrant flowers.

According to the Angiosperm Phylogeny Group IV (APG IV) classification system, *J. sambac* is an angiosperm belonging to the eudicot clade Asterids, placed under the order Lamiales and family Oleaceae. *J. sambac* is an evergreen to semi-evergreen, bushy shrub with profuse branching, bearing simple, opposite ovate to elliptic leaves. Flowers are axillary or terminal, borne singly or in cymes, actinomorphic and salverform with five to nine corolla lobes, two epipetalous stamens and a bicarpellary superior ovary. Anthesis occurs in the evening with peak fragrance emission, and fruit set is rare, with berries formed occasionally.

The floral morphology of *J. sambac* exhibits considerable variation and is commonly categorized based on corolla structure into single-petal (SP), double-petal (DP), and multi-petal (MP) types. These floral forms influence flower yield, stress tolerance and aroma characteristics (Wang *et al*., 2022b; Fang *et al*., 2024; Zhang *et al*., 2025). Genome size estimation has revealed approximate genome sizes of 547 Mb in SP, 580 Mb in DP, and 495.89 Mb in MP types (Wang *et al*., 2022a; Zhao *et al*., 2025). Cytological analyses indicate that DP jasmine maintains a stable diploid karyotype with 13 chromosome pairs, whereas SP jasmine exhibits karyotypic instability with a mixture of diploid and triploid cells, which may contribute to its reduced fertility and adaptability under cultivation (Wang *et al*., 2022a).

3. Ethnobotanical and traditional medicinal uses

In traditional and ethnobotanical systems, *J. sambac* has been widely utilized as both an edible and medicinal plant. The flowers are considered edible and are commonly used in herbal teas, flavouring agents, and aromatic preparations, where their volatile constituents contribute to both culinary appeal and therapeutic effects. In folk medicine, flower-based infusions are traditionally employed to relieve coughs, colds, mild nervous disorders, and are valued for their calming and sedative properties (Lim, 2014).

In classical Ayurvedic literature, *J. sambac* is described as possessing a bitter and astringent taste, heating potency, and tridosha-balancing (Tridoshahara) properties, which underpin its use in a broad range of systemic and localized ailments (Gondkar *et al*., 2024). The plant is traditionally indicated for the management of shiroroga (head-related disorders, including headaches), akshiroga (eye diseases), mukharoga (oral cavity disorders), dantaroga (dental ailments), kushta (skin diseases), vrana (ulcers and wounds), and visphota (boils and blisters). Leaf and flower preparations are commonly applied externally for their antiseptic, antiinflammatory, analgesic and wound healing effects, while leaf decoctions or chewed leaves are used to alleviate toothache, mouth ulcers and gum inflammation (Gondkar *et al*., 2024).

Traditional medicinal practices across South and SouthEast Asia also document the use of *J. sambac* in women's health care. Preparations derived from flowers and leaves are employed to manage dysmenorrhea (painful menstruation) and menorrhagia (excessive menstrual bleeding), reflecting its role in alleviating pain and regulating menstrual flow (Silalahi *et al*., 2023).

The plant has a strong ethnomedicinal history in the treatment of skin-related disorders, including ringworm, leprosy and chronic skin infections. Topical application of leaf and flower extracts is traditionally practiced for their antiseptic, soothing, and antimicrobial properties, supporting wound healing and infection control (Silalahi *et al*., 2023). Root extracts have also been traditionally employed as remedies for paralysis and snakebite, although such uses are less common and largely confined to localized ethnomedicinal practices (Mourya *et al.,* 2017). In addition to its topical and internal applications, jasmine aroma particularly due to volatile compounds such as linalool has been associated with modulation of autonomic nervous responses (Ashraf *et al.,* 2024). Aromatherapy using *J. sambac* flowers or essential oil has been linked to relaxation, stress reduction, and mood enhancement, lending scientific support to its traditional use as a mild sedative and anxiolytic agent (Ashraf *et al.,* 2024).

4. Phytochemical constituents

Qualitative phytochemical analyses of *J. sambac* have revealed the presence of a wide range of volatile and non-volatile secondary metabolites distributed across different plant parts, particularly the flowers (Table 1). Analytical techniques such as thin-layer chromatography (TLC) combined with standard chemical tests have been employed, with ethanolic and methanolic flower extracts commonly used due to their efficiency in extracting polar and semi-polar compounds. The volatile oil content in terms of absolute oil ranges from 0.02 to 1.28% on fresh petal weight basis, and is predominated by aromatic volatile compounds, with benzyl acetate as the major constituent (Akram *et al.,* 2017; Younis *et al.,* 2011). Other prominent volatile compounds reported include linalool, benzyl alcohol, methyl jasmonate, indole, eugenol, farnesene, nerolidol, methyl anthranilate, geraniol, and caryophyllene (Hong *et al.,* 2024; Rescigno *et al*., 2025). In addition, glycosidic precursors of benzyl and phenylethyl alcohols have been identified, which contribute to fragrance development and stability (Inagaki, 1995). Non-volatile phytochemicals identified in *J. sambac* include flavonoids such as quercetin and kaempferol, along with saponins, sterols (particularly β-sitosterol), phenolic compounds, coumarins, and cardiac glycosides. However, the presence of alkaloids, anthraquinones, and tannins in flower extracts has been reported to be nil or in trace amounts depending on the extraction methods and analytical approaches (Kunhachan *et al*., 2012).

5. Pharmacological and biological activities

The chemical diversity of volatile and non-volatile secondary metabolites in *J. sambac* makes it a potential medicinal plant exhibiting a wide array of pharmacological and health benefit effects (Table 2).

Table 1: Active biochemical constituents identified through analytical methods in various plant parts

S.No.	Plant part	Bioactive compounds	Analytical methods	References
1	Root	Linalool, Benzyl acetate, Benzyl benzoate	GC-MS	Ahmed *et al*., 2016
		Flavonoids, Linalool, Indole, Benzyl acetate, Glycosides, Tannins	Phytochemical analysis	Begum *et al*., 2026
2	Stem	Phenols, Flavonoids, Tannins, Saponins, Glycosides	Phytochemical analysis	Sabharwal *et al.,* 2012
		Isoamyl nitrite, Benzophenone	GC-MS, TLC	Mohd Padli *et al*., 2019
		Alkaloids, Saponins, Flavonoids, Tannins	Phytochemical analysis-FTIR	Rafique *et al*., 2023
		Benzenoids, Eicosapentaenoic acid, Methyl ester, Indoles, Siloxanes	GC-MS	Keerthivasan *et al.,* 2024
3	Leaf	Phenols, Flavonoids, Quercetin, Kaempferol glycosides, Lignans, Secoiridoids, Oleuropein, Molihauside, Sambacoside	FTIR, HPLC-PDA-MS/MS	El-Hawary *et al.,* 2019
		Alkaloids, Saponins, Flavonoids, Glycosides	Phytochemical analysis	Tomar and Rijhwani, 2021
		Phenols, Flavonoids, Saponins, Coumarins, Rutin, Isoquercetin	Phytochemical analysis, HPLC	Khan *et al.,* 2021
		Phenols, Flavonoids	Phytochemical analysis, HPLC/MS	Umar *et al.,* 2023
		Phenols, Flavonoids, Tannins, Terpenoids	Phytochemical analysis	Venkatesha *et al.,* 2025
		Flavonoids, Alkaloids, Glycosides, Tannins, Saponins, Triterpenoids	Phytochemical analysis	Begum *et al.,* 2026
4	Flower	Benzyl acetate, E-E-Farnesene, Z-3-Hexenyl benzoate, Benzyl alcohol, Linalool, Methyl anthranilate	GC-MS	Edris *et al.,* 2008
		cis-3-Hexenyl acetate, (*E*)-β-Ocimene, Linalool, Benzyl acetate, (*E,E*)-α-Farnesene	GC-qMS Tricosene	Pragadheesh *et al.,* 2011
		Benzyl acetate, Benzyl alcohol, Indole, Methyl anthranilate, (3E,6E)-A-Farnesene, (Z)-3-Hexenyl benzoate, 1(10),5-Germacradien-4-ol, Methyl linolenate, Tricosene	GC-MS	Braun and Sim, 2012
		Farnesene, Benzyl alcohol, Nerolidol, Linalool,	GC-MS	Khidzir *et al.,* 2015
		Cadinol, Linalool, Benzyl acetate	SFE	Ye *et al.,* 2016
		Terpenoids, Phenols, Flavanoids	Phytochemical analysis	Widowati *et al.,* 2018
		Benzyl acetate, Linalool, Nerolidol, Farnesene, *Cis*-Jasmone	SPME, GC-MS	Issa *et al.,* 2020
		Dimethylsulfoxonium formylmethylide, Acetic acid, Phenylmethyl ester, Diethyl phthalate, Phenylethyl alcohol	GC-MS	Jha *et al*., 2022
		Benzyl alcohol, Benzyl acetate, Benzyl benzoate.	GC-MS	Ghissing *et al.,* 2022
		Methyl anthranilate	UPLC-MS	Chen *et al.,* 2023
		Caryophyllene, Geraniol, Linalool, α-Farnesene, β-Ocimene, Methyl anthranilate, Methyl salicylate, Benzene acetaldehyde, Hexanal	Metabolome analysis	Hong *et al.,* 2024
		Linalool, α-Farnesene, Germacrene-D, Geranyl linalool, D-Limonene, Benzenoids	GC-MS	Vishnupandi *et al.,* 2025
5	Callus	Alkaloids, Glycosides, Flavanoids, Terpines, Tannin, Resin, Salicylic acid.	Phytochemical analysis	Joy and Raja, 2008

GC-MS: Gas Chromatography-Mass Spectrometry; GC-qMS: Gas Chromatography quadrupole Mass Spectrometry; TLC: Thin-Layer Chromatography; FTIR: Fourier Transform Infrared spectroscopy; HPLC-PDA-MS/MS: High-Performance Liquid Chromatography with Photodiode Array Detector and Tandem Mass Spectrometry; SPME: Solid Phase Micro Extraction; SFE: Subcritical Fluid Extraction; UPLC-MS: Ultra Performance Liquid Chromatography-Mass Spectrometry.

5.1 Antimicrobial activity

The antimicrobial properties of *J. sambac* have been widely documented using essential oils, crude extracts, callus-derived metabolites, and nano material-based formulations. Studies employing agar diffusion, disk diffusion, and minimum inhibitory concentration (MIC) assays have demonstrated broad spectrum antibacterial and antifungal activity against clinically relevant Gram-positive bacteria *Staphylocoocus aureus*, Gram-negative *Escherichia coli*, and fungal pathogens such as *Candida albicans* and *Aspergillus niger* (Rakhmawati, 2022; Lakshmi *et al.,* 2024; Rizal and Wan Abdul Razak, 2024)

Essential oil derived from *J. sambac* produced clear zones of inhibition against a range of bacterial and fungal strains, with Gram-positive bacteria exhibiting greater sensitivity (Jha *et al*., 2022). The antimicrobial activity of flower extracts and essential oils has been linked to fragrance-associated constituents such as benzyl acetate, citronellol and linalool, which are known to disrupt microbial membranes and metabolic processes (Wu *et al*., 2021). Supporting this, Jha *et al*. (2022) observed inhibition zones ranging from 9 to 18 mm and MIC values between 104 to 291 µg/ml for essential oil and methanolic extracts, confirming both antibacterial and antifungal potential. Recent advances have explored nanotechnology assisted antimicrobial strategies. Silver and copper nanoparticles biosynthesized from leaf extracts and essential oil of *J. sambac* exhibited enhanced antibacterial activity against *S. aureus* and *E. coli*, with maximum inhibition at 260 µg/ml (Bidan and Al-Ali**,** 2022; 2024; 2025). The increased efficacy was attributed to the synergistic interaction between bioactive constituents and nanoparticles, leading to improved bactericidal performance.

Leaf-derived extracts have also shown substantial antimicrobial effects. Anima *et al*. (2019) evaluated ethanolic leaf extracts in the context of wound healing and reported strong activity against *Pseudomonas aeruginosa*, a common wound pathogen, with an inhibition zone of 14.67 ± 0.9 mm and an MIC of 0.78 mg/ml. Similarly, Rizal and Wan Abdul Razak, (2024) demonstrated that ethanolic and aqueous leaf extracts inhibited *E. coli* and *A. niger*, with aqueous extracts showing particularly strong antifungal activity (up to 24.0 ± 0.58 mm inhibition zone). These findings underscore the relevance of solvent polarity in extracting antimicrobial constituents.

In vitro studies using tissue culture derived materials further support the antimicrobial capacity of *J. sambac*. Joy and Raja, (2008) reported that ethanolic callus extracts exhibited superior antibacterial activity against *Staphylococcus albus*, *Proteus mirabilis*, and *Salmonella typhii* compared to other plant extracts, suggesting that *in vitro* derived biomass may serve as a sustainable source of antimicrobial metabolites. Several review-based evaluations have consolidated these findings. Jian *et al*. (2023) similarly highlighted repeated reports of growth inhibition against both Gram-positive and Gram-negative bacteria using essential oils and hydromethanolic extracts, supporting the classification of *J. sambac* as a broad spectrum antimicrobial plant. The activity is largely attributed to terpenoids, phenolics, and aromatic alcohols, with enhanced efficacy observed in nanoparticle based formulations.

5.2 Antioxidant activity

Oxidative stress is a key contributor to the development of several chronic and metabolic disorders, and the antioxidant potential of *J. sambac* has therefore been widely investigated. Antioxidant activity of *J. sambac* has been assessed using a battery of *in vitro* assays measuring free radical scavenging capacity, reducing power, metal-chelating ability, and inhibition of lipid peroxidation, with strong correlations reported between antioxidant efficacy and phenolic-flavonoid content.

Essential oils and extracts of *J. sambac* have been tested for concentration-dependent free radical scavenging activity (Jian *et al*., 2023). Lakshmi *et al*. (2024) evaluated the antioxidant activity of *J. sambac* essential oil using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay and the 2,22 -azino-bis (3-ethylbenzo-thiazoline-6-sulfonic acid) (ABTS) radical cation decolorization assay, which assess hydrogen-donating and electron-transfer capacity, respectively. The essential oil exhibited marked antioxidant activity over a concentration range of 10-50 µg/ml, with maximum radical scavenging activity of 66% observed at 50 µg/ml.

Besides the essential oil, comparable antioxidant activity has also been reported for flower, leaf, and hydroalcoholic extracts. Significant dose-dependent antioxidant activity has been demonstrated using DPPH and ferric reducing antioxidant power (FRAP) assays, indicating effective neutralization of reactive oxygen species and enhanced reducing capacity (Widowati *et al*., 2018). Methanolic and hydroalcoholic leaf extracts showed strong DPPH scavenging activity with a half-maximal inhibitory concentration (IC_{50}) of approximately 120 µg/ml (Khan *et al*., 2021; Khidzir *et al*., 2015), while multiple studies reported IC_{50} values predominantly in the range of 50-150 µg/ml across DPPH and ABTS assays (Nomier *et al*., 2024; Mohamed Asik and Kumar, 2023), confirming robust antioxidant efficacy.

Wu *et al*. (2021) evaluated flower extract mixtures by employing multiple complementary antioxidant assays such as DPPH and ABTS radical scavenging assays, reducing power assay, β-carotene bleaching (BCB) assay for lipid peroxidation inhibition, and ferrous ion chelating (FIC) assay to capture different mechanisms of action. The extracts exhibited consistent, concentration-dependent antioxidant responses across all assays, demonstrating the ability to neutralize free radicals, chelate pro-oxidant metal ions, and suppress oxidative chain reactions. Similar findings were reported for methanolic flower extracts and essential oil using DPPH and ABTS-based assays (Khidzir *et al*., 2015; Jian *et al*., 2023).

In addition to direct radical scavenging, antioxidant activity in *Jasminum* species has been closely linked to phytochemical composition. Extracts rich in flavonoids and phenolic acids exhibited superior antioxidant activity across DPPH, ABTS, FRAP, and lipid peroxidation inhibition assays. These extracts were also associated with enhancement of endogenous antioxidant enzymes, including superoxide dismutase (SOD) and catalase (CAT), suggesting a dual mechanism involving both direct reactive oxygen species scavenging and reinforcement of cellular antioxidant defense systems (Marappan *et al*., 2025).

5.3 Antiinflammatory activity

Inflammation underlies the progression of numerous acute and chronic pathological conditions, and the anti-inflammatory potential of *J.*

sambac has been evaluated using *in vivo* animal models, *in vitro* enzyme and cytokine inhibition assays, and topical or clinical comparative studies. The observed effects are dose-dependent and appear to be mediated through suppression of pro-inflammatory enzymes, cytokines, and modulation of key inflammatory signaling pathways in both acute and proliferative phases of inflammation.

In an *in vivo* experimental study, Bhangale *et al*. (2012) reported that ethanolic leaf extracts of *J. sambac* administered at 200 and 400 mg/kg significantly reduced carrageenan-induced paw edema in rats. Similarly, Sengar *et al.* (2015) evaluated ethanolic root extracts at doses of 100, 200, and 400 mg/kg in albino rats using both acute (carrageenan-induced paw edema) and sub-chronic (cotton pellet-induced granuloma) inflammation models, reporting the highest inhibition rates at 400 mg/kg, with measurable antiinflammatory effects observed at the 2nd, 3rd, 4th, and 6th h of post-treatment. Significant antiinflammatory effects of jasmine essential oil have also been observed to be mediated by a key pain receptor TRPV 1 (transient receptor potential vanilloid 1) (Jaffal *et al*. 2025).

Topical and comparative studies further support the clinical relevance of *J. sambac*. Belango *et al*. (2016) conducted a scratch test in guinea pigs to compare the anti-inflammatory efficacy of *J. sambac* gel and diclofenac emulgel, demonstrating that a 1% *J. sambac* extract gel exhibited superior anti-inflammatory activity. Ain *et al*. (2024) similarly compared *J. sambac* gel with diclofenac using the numerical pain rating scale (NPRS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and global pain relief scales, reporting faster onset of action for *J. sambac*. The enhanced activity was attributed to bioactive compounds such as rutin, quercetin, isoquercetin, β-sitosterol, and linalool.

At the molecular and cellular level, several *in vitro* studies have elucidated the mechanisms underlying the anti-inflammatory effects of *J. sambac*. Lakshmi *et al*. (2024) demonstrated that *J. sambac* essential oil significantly inhibited pro-inflammatory mediators in membrane stabilization based inflammatory assays at concentrations of 10-50 µl/ml. Reviews and experimental studies have consistently reported inhibition of cyclooxygenase-2 (COX-2), tumour necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), nitric oxide (NO), and nuclear factor kappa-B (NF-κB) signaling pathways, with inhibition levels ranging from approximately 80 to 95% at extract concentrations of 1000-2000 µg/ml (Ain *et al.,* 2024; Marappan *et al.,* 2025).

5.4 Analgesic activity

Pain management represents an important therapeutic area closely associated with, but distinct from, inflammation. The available evidence indicates that *J. sambac* exerts significant analgesic effects through modulation of pain perception and nociceptive signalling pathways. Initial indications of analgesic potential were reported by Rahman *et al*. (2011), who observed bioactivity in crude ethanolic leaf extracts during preliminary screening assays, prompting further *in vivo* validation.

Subsequent studies employed established chemical and thermal induced nociception models to substantiate and quantify analgesic efficacy. Petroleum ether leaf extracts evaluated using acetic acid induced writhing (peripheral nociception), tail immersion, and hot plate assays produced significant, dose-dependent analgesic effects at 200 and 400 mg/kg, with maximal writhing inhibition of 67.49% at the higher dose, comparable to standard analgesics (Bhangale *et al.,* 2012). These findings indicate involvement of both peripheral and centrally mediated pain pathways.

Consistent results were reported with methanolic root extracts, which significantly prolonged reaction times in tail-flick assays and reduced writhing responses in mice at doses of 200 and 400 mg/kg, further confirming dual-mode analgesic action (Bhowmik *et al*., 2013). A phytochemically linked investigation using ethanolic root extracts standardized to 4.25% (w/w) hesperidin demonstrated marked increases in tail-flick latency and suppression of writhing behaviour, highlighting the contributory role of flavonoid constituents in nociceptive modulation (Sengar *et al*., 2015).

More recent validation using methanolic extracts across a broader dose range (100-400 mg/kg) in the writhing mice model corroborated these findings, with significant analgesic effects observed at higher doses, likely mediated through inhibition of pain-inducing chemical mediators and reduced peripheral nerve sensitivity (Rattan, 2023). While these analgesic properties may complement the plant's antiinflammatory activity, the use of distinct pain models indicates an independent pain-modulating potential of *J. sambac*.

5.5 Anticancer activity

The anticancer potential of medicinal plants is commonly evaluated using *in vitro* cytotoxicity assays such as 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay, Cell Counting Kit-8 (CCK-8), and neutral red uptake assays, which assess cancer cell viability, metabolic activity, and membrane integrity, followed by *in vivo* tumour models including Dalton's ascites lymphoma to validate therapeutic efficacy. These approaches are often complemented by mechanistic studies examining apoptosis induction, cell-cycle arrest, and modulation of oncogenic signalling pathways. Using such experimental frameworks, *J. sambac* has demonstrated strong anticancer activity, with its extracts, essential oils, and bio-synthesised nanoparticles showing dose-dependent cytotoxicity against multiple human cancer cell lines, particularly breast and liver cancers, supporting its potential as a source of plant-derived anticancer agents.

Based on *in vitro* evaluations, flower essential oil, methanolic leaf and flower extracts showed significant dose-dependent cytotoxicity against breast (MCF-7, MDA-MB-231), liver (HepG2), cervical (HeLa), and bladder (5637) cancer cell lines in MTT, CCK-8, and neutral red uptake assays, at concentrations ranging from 10-400 µg/ml (Kalaiselvi *et al*., 2012; Kalaiselvi *et al.,* 2013; Lakshmi *et al*., 2024; George *et al.,* 2025). Bioactive compounds isolated from roots further exhibited potent cytotoxicity against MCF-7 cells at micromolar concentrations (Olatunde *et al*., 2023). Compared with crude extracts, green-synthesised silver nanoparticles mediated by *J. sambac* extracts demonstrated enhanced antiproliferative activity, achieving markedly lower IC_{50} values ($\leq$30 µg/ml), likely due to improved cellular uptake (El-Hawary *et al*., 2019; Bidan and Al-Ali, 2024; Nomier *et al*., 2024). Mechanistic studies indicate that these effects are mediated through apoptosis induction, cell-cycle arrest, and modulation of oncogenic signalling pathways including PI3K/Akt, MAPK, and Wnt/β-catenin (Marappan *et al*., 2025). The antitumour efficacy of *J. sambac* has been further substantiated *in vivo* using Dalton's ascites lymphoma models in Swiss albino mice. Oral administration of methanolic extracts (100 mg/kg body weight)

resulted in significant reductions in tumour cell burden, ascitic fluid volume, and tumour-associated biochemical markers, along with normalization of altered lipid profiles and antioxidant parameters (Kalaiselvi *et al*., 2012; Kalaiselvi *et al.,* 2013). Additionally, the treatment significantly suppressed the activity of cancer-associated enzymes such as β-glucuronidase, γ-glutamyl transferase, and 52 - nucleotidase, indicating systemic antitumour effects.

5.6 Antidiabetic activity

The antidiabetic potential of *J. sambac* has also been investigated through a wide range of experimental approaches encompassing phytochemical characterization, *in vitro* enzyme inhibition assays, *in vivo* diabetic animal models, and *in silico* molecular docking studies. Collectively, these investigations indicate that the antidiabetic property of *J. sambac* stems from a multi-mechanistic glucose-regulatory activity mediated by modulation of carbohydrate metabolism, insulin secretion, oxidative stress, and diabetes-associated molecular targets.

Evidence from *in vivo* studies demonstrated that phenolic-rich leaf extracts significantly reduced fasting blood glucose and glycosylated haemoglobin (HbA1c) levels in alloxan-induced diabetic rats, accompanied by restoration of serum insulin levels and normalization of antioxidant enzymes (SOD, CAT, and glutathione peroxidase), along with reduced lipid peroxidation. The observed effects were correlated with the presence of rosmarinic acid and *p*-coumaric acid identified by HPLC analysis (Umar *et al*., 2023). Similarly, significant glucose-lowering and hypolipidemic effects of aqueous and ethanolic root extracts were observed in streptozotocin-induced diabetic rats, with the higher aqueous dose exhibiting efficacy comparable to the standard antidiabetic drug glibenclamide (Ingawale, 2025). These findings were further supported by studies that documented consistent reductions in fasting blood glucose levels following treatment with leaf and flower extracts in diabetic animal models (Rambabu and Patnaik, 2014; Saleem *et al.,* 2025). Water-soluble polysaccharides from *J. sambac* tea have also been investigated for their protective effects against high glucose induced injury in pancreatic islet (RIN-m5F) cells using a CCK-8 cell viability assay. These water-soluble fractions significantly improved cell viability under hyperglycemic conditions, mitigating glucose induced cytotoxicity, potentially by enhancing islet cell protection and insulin secretion (Tang *et al*., 2021).

At the *in vitro* level, *J. sambac* is known to interfere with intestinal carbohydrate digestion through inhibition of key carbohydrate-metabolizing enzymes. A concentration dependent inhibition/ suppression of α-amylase and α-glucosidase activities by aqueous leaf extracts and their correlation with higher levels of total phenolic and flavonoid contents suggest attenuation of postprandial hyperglycemia by delaying carbohydrate breakdown and subsequent glucose absorption (Saleem *et al*., 2025; Balkrishna *et al*., 2021).

5.7 Cardioprotective and antihypertensive effects

Integrated *ex vivo* and *in vivo* cardiovascular models have been used to assess the cardioprotective potential of *J. sambac.* Crude leaf and ethanolic flower extracts produced significant vasorelaxation in endothelium-intact aortic ring preparations, indicating smooth-muscle relaxation predominantly mediated through nitric oxide dependent endothelial pathways (Khan *et al*., 2021; Kunhachan *et al*., 2012). In an adrenaline-induced myocardial infarction model in rabbits, oral administration of the extract markedly reduced serum cardiac injury biomarkers, including creatine kinase-MB (CK-MB), lactate dehydrogenase (LDH), cardiac troponin, C-reactive protein (CRP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP), in addition to attenuation of myocardial necrosis, edema, and inflammatory cell infiltration (Khan *et al.,* 2021). Complementary evidence from hyperglycemic rat models demonstrated dose-dependent vasorelaxation and improved cardiac biomarkers, aiding in prevention of diabetic induced cardiomyapthy and heart failure following extract administration (Umar *et al.,* 2023).

5.8 Immunomodulatory and antiallergic activity

Mast cells are tissue-resident immune cells that play a pivotal role in allergic inflammation and immune regulation through the release of preformed and newly synthesized mediators, including histamine, proteases, cytokines, and chemokines. Activation of mast cells, commonly *via* immunoglobulin E (IgE) mediated signalling, leads to degranulation and subsequent initiation of immediate hypersensitivity reactions, vasodilation, increased vascular permeability, and recruitment of inflammatory cells. Consequently, stabilization of mast cells represents a key therapeutic strategy for the modulation of allergic and inflammatory immune responses.

The immunomodulatory and antiallergic potential of *J. sambac* has been demonstrated in mast cell based experimental models. Jain (2018) reported that a hydroalcoholic (50:50) leaf extract significantly inhibited compound 48/80-induced mast cell degranulation *in vitro*, indicating a direct mast cell-stabilizing effect, with no observed toxicity up to 2000 mg/kg body weight. Phytochemical analyses revealed the presence of flavonoids, phenolic compounds, saponins, tannins, terpenoids, glycosides, and steroids, which are known to modulate immune signalling pathways, suppress mediator release, and attenuate oxidative stress. In addition to antiallergic activity, immuno-stimulatory effects of *J. sambac* have been attributed to its non-volatile polysaccharide fraction. Huang *et al*. (2023) isolated water-soluble polysaccharides from jasmine tea flower waste and characterized them as being predominantly composed of galactose and arabinose residues. *In vitro* assays demonstrated that these polysaccharides significantly enhanced macrophage proliferation and stimulated dose-dependent production of immune mediators, including nitric oxide and pro-inflammatory cytokines, indicating activation of innate immune responses. While these findings highlight the dual immunomodulatory nature of *J. sambac*, triggering both suppression of allergic mediator release and stimulation of macrophage-mediated immunity, the reported effects are largely based on *in vitro* models. Further *in vivo* studies and mechanistic investigations are required to elucidate the physiological relevance, signalling pathways involved, and therapeutic applicability of these immune-modulating effects.

5.9 Antimelanogenic and antiaging activity

The antityrosinase potential of *J. sambac* has been evaluated using mushroom tyrosinase inhibition assays, a widely accepted preliminary model for assessing antimelanogenic activity. Wu *et al*. (2021) reported that several flower extract formulations exhibited dose-dependent inhibition of tyrosinase activity, with the exception of the 100% supercritical fluid extract. The observed IC_{50} values indicated effective suppression of melanin synthesis, making *J.*

sambac extracts as natural skin-whitening agents. However, as mushroom tyrosinase differs structurally and functionally from human tyrosinase, and as the study did not include validation in human melanocyte cell lines or *in vivo* pigmentation models, these results are considered preliminary. In addition to antimelanogenic effects, *J. sambac* also exhibits antiaging potential by protecting skin structural proteins through inhibition of extracellular matrix-degrading enzymes such as elastase and collagenase, further expanding its application in cosmeceutical formulations (Widowati *et al*., 2018). However, the anticollagenase and antielastase activity was comparatively lower than hesperidin and eugenol, which might be due to absence of tannins in the ethanolic flower extracts. Hence, investigations employing human-relevant systems and bioactive compound isolation are required to substantiate the clinical relevance of these cosmetic applications.

5.10 Neuroprotective activity

Neuroprotective effects of *J. sambac* have been reported through both enzymatic and behavioural models. Gupta and Kulshreshtha, (2018) demonstrated significant *in vitro* inhibition of acetylcholinesterase (AChE), a key enzyme involved in cholinergic neurotransmission, with IC_{50} values of approximately 200 µg/ml. *In vivo* studies further indicated improved cognitive performance in animal maze tests following extract administration at doses of 200-400 mg/kg, suggesting potential benefits against cognitive impairment. While these findings support a neuroprotective role for *J. sambac*, the observed effects were derived from crude extracts with moderate inhibitory potency compared to standard AChE inhibitors. Moreover, the lack of validation using molecular markers of neurodegeneration, such as oxidative stress indices, amyloid-β accumulation, or tau pathology, and the absence of blood-brain barrier permeability assessments limit translational interpretation.

5.11 Gastroprotective and antiulcer activity

The gastroprotective activity of *J. sambac* is known to be associated with its antistress and cytoprotective properties. Methanolic leaf extracts evaluated using a swimming stress-induced gastric ulceration model in rats, resulted in significant reduction in ulcer index and gastric lesion severity compared with untreated stressed controls, indicating effective protection against stress-mediated gastric mucosal damage (Baby, 2010). However, detailed interpretation of the underlying pathways relies on examining the gastric mucus secretion, antioxidant enzyme levels, or inflammatory mediators.

5.12 Wound healing activity

Both *in vivo* and *in vitro* models have been used to explore the wound healing potential of *J. sambac* leaves and flowers. In excision and incision wound models in rats, ethanolic leaf extract of *J. sambac* significantly enhanced wound contraction, shortened epithelialization period, increased skin breaking strength, and elevated collagen deposition, as indicated by increased hydroxyproline content (Anima *et al*., 2019). Complementary *in vitro* studies showed that flower extracts of *J. sambac* were non-cytotoxic and significantly promoted fibroblast (NIH 3T3) viability at concentrations of 31.25–250 µg/ml, and were successfully incorporated into wound dressing films with favourable physical properties. In diabetes-associated complications, the enhanced fibroblast proliferation and antioxidant activity suggest ancillary benefits that may contribute to improved tissue repair under hyperglycemic conditions (Eakwaropas and Wisidsri, 2019).

Table 2: Bioactive compounds, analytical methods, and pharmacological activities identified from different plant parts

Plant part	Extract	Analytical methods	Bioactive compounds	Pharmacological assays	Laboratory models tested	Pharmaceutical property	References
Leaf	Methanol	Phytochemical analysis	Jasmintides, Sterols, Tannins	Swimming endurance test, Histopathology	Rat	Antistress	Baby, 2010
Leaf	Ethanol	Phytochemical analysis	Flavonoids, Glycosides, Tannins, Alkaloids	Writhing test	Swiss albino mice	Analgesic	Rahman *et al.,* 2011
				Lethality bioassay	Brine shrimps	Cytotoxic	
Leaf	Ethanol	Phytochemical analysis	Flavonoids, Alkaloids, Tannins, Phenols, Saponins, Steroids	Elevated plus maze test	Swiss albino mice	Anxiolytic	Ramdas Bhat *et al.,* 2025
Leaf	Ethanol	Phytochemical analysis	Flavonoids, Alkaloids, Phenols, Tannins	Elevated plus maze test, Dark box, Open field test, Forced swim test	Swiss albino mice	Anxiolytic	Dangi *et al.,* 2026
Leaf	Ethanol	Phytochemical analysis	Steroids, Terpenoids, Saponins, Tannins, Phenols	Agar well diffusion test	Bacteria, Fungi	Antimicrobial	Anima *et al.,* 2019
				DPPH assay	*In vitro*	Antioxidant	
				Excision and incision wound model, Histopathology	Albino rats	Wound healing	
Leaf	Ethanol	UPLC-Q-TOF -MS/MS	Betaine, L-Malic acid, Citric acid	AI based model prediction	Mice	Antihyper lipidemic	Yao *et al.,* 2024
Leaf	Petroleum ether	Phytochemical analysis	Alkaloids, Flavonoids, Glycosides, Steroids	Writhing Test, Tail immersion test, Hot Plate Method	Wistar rats	Analgesic	Bhangale *et al.,* 2012
				Carrageenan induced rat p aw oedema	Swiss albino mice	Antiinflammatory	

Leaf	Petroleum ether	Phytochemical analysis	Flavonoids, Tannins, Phenols, Steroids, Terpenoids, Saponins, Glycosides	Agar disc diffusion test	Bacteria, Fungi	Antimicrobial	Gowdhami *et al.,* 2015
Leaf	Aqueous	Phytochemical analysis	Phenols, Flavonoids	α-amylase inhibition assay	*In vitro*	Antidiabetic	Saleem *et al.,* 2025
				Anucleated cells lysis assay	*In vitro*	Low hemolytic	
				Agar well diffusion test	Bacteria	Antimicrobial	
				DPPH assay	*In vitro*	Antioxidant	
Leaf	Ethanol and Aqueous	-	Flavonoids, Coumarins	Disk diffusion test	Bacteria, Fungi	Antimicrobial	Rizal and Wan Abdul Razak, 2024
Leaf	Aqueous extract, Essential oil	FTIR	Coumarins, Saponins	MTT assay	Human breast cancer MCF-7 cell line	Anticancer	Bidan and Al-Ali, 2022; 2024
Flower	Methanol	GC-MS	Farnesene, Nerolidol, Benzyl alcohol, Linalool, α-Cadinol	DPPH assay	*In vitro*	Antioxidant	Khidzir *et al.,* 2015
Flower	Methanol	Phytochemical analysis	Alkaloids, Flavonoids, Cardioglycosides, Saponins, Coumarins, Phenolics, Quinones, Steroids, Betacyanins, Terpenoids, Tannins	DPPH assay	*In vitro*	Antioxidant	Suaputra *et al.,* 2021
Flower	Ethanol	Phytochemical analysis	Alkaloids, Flavonoids, Quinone	Pancreatic lipase assay	Mice	Antiobesity	Ramadhan, 2015
Flower	Ethanol	Phytochemical analysis, GC-MS	Tannins, Flavonoids, Saponin, Phenol, 9,12,15-Octadecatrienal, Octadecanoic acid, 9,12-Octadecadienoic acid	Disk diffusion test	Bacteria, Fungi	Antimicrobial	Rakhmawati, 2022
Flower	Ethanol	TLC, HPLC	Coumarins, Cardiacglycosides, Saponins, Flavonoids, Phenolics, Steroids	Vasodilatation effect test	Wistar rats	Vasodilatory	Kunhachan *et al.,* 2012
Flower	Ethanol	Phytochemical analysis, HPLC	Terpenoids, Phenols, Flavonoids, Hesperidin	Collagenase, Hyaluronidase, Elastase assays	*In vitro*	Antiaging	Widowati *et al.,* 2018
				DPPH scavenging activity, ABTS, FRAP-reducing activity	*In vitro*	Antioxidant	
Flower	Hexane extract, Essential oil	GC-MS	Linalool, Benzyl acetate, Patchulene, Humulene, Squalene, Spathulenol, Sitosterol, Terpenes, Terpenoids	MTT assay, Wound healing assay, AO Et/Br staining, Flow cytometry	Human Mammalian cancer cell MCF-7	Anticancer	Lakshmi *et al.,* 2024
				RBC membrane stabilization test, Heat-induced hemolysis, Protein denaturation assay	Human blood samples	Anti-inflammatory	
				Disc diffusion test	Bacteria, Fungus	Antimicrobial	
				DPPH and ABTS Assay	*In vitro*	Antioxidant	
Flower	Essential oil	GC-MS	-	Writhing test, Immersion tail-flick test	Mice	Analgesic	Jaffal *et al.,* 2025
				Carrageenan induced rat paw Oedema	Mice	Antiinflammatory	
Flower	Essential oil	GC-MS	Benzyl acetate, Linalool, Phytol, Farnesol, Benzyl alcohol, Cresol	Kirby-bauer disk diffusion test	Bacteria, Fungi	Antimicrobial	Thaweboon *et al.,* 2018

Flower	Essential oil	GC-MS	DiMethylsulfoxonium formylmethylide, Acetic acid, Phenylmethyl ester, Diethyl phthalate, Phenylethyl alcohol, p-Cresol, Linalool	Agar disc diffusion test Antimalarial analysis	Bacteria, Fungi	Antimicrobial	Jha *et al.,* 2022
				DPPH assay	*In vitro*	Antioxidant	
Flower	Super critical fluid	Phytochemical analysis	Benzyl acetate, B-Pinene, Hexadecan-1-Ol, 9,12, 15-Octadecatrienoic acid, Citronellol, Octacosane, Squalene, Floridanine, Jasminolactone	DPPH, ABTS assay	*In vitro*	Antioxidant	Wu *et al.,* 2021
				Tyrosinase assay	*In vitro*	Antimelanogenic	
Root	Dichloro methane	HPLC, NMR, HRESIMS	Karanjin, Germacrone, Quercetin	Cell counting kit-8 (CCK8)	Mammalian cancer cell MCF-7	Anticancer	Olatunde *et al.,* 2023
				Agar well diffusion test	Bacteria	Antimicrobial	
Whole Plant	Methanol	GC-MS	Cefazolin, Dl-Citrulline, Thiocyanic acid, Limonene, 5,3',4'-Trihydroxyflavone, 4-Fluoro histidine	Sulforhodamine B (SRB) assay	Human Liver cancercancer cell line (HEPG2)	Anticancer	George *et al.,* 2025
				DPPH assay	*In vitro*	Antioxidant	
Callus	Ethanol	Phytochemical analysis	Alkaloids, Glycoside, Flavonoid, Terpines, Tannin, Resin, Salicylic acid	Agar disc diffusion test	Bacteria	Antimicrobial	Joy and Raja, 2008

* DPPH-2,2-diphenyl-1-picrylhydrazyl scavenger; FRAP-Ferric Reducing Antioxidant Power; ABTS-2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid); MCF-Michigan Cancer Foundation-7; HRESIMS-High-Resolution Electrospray Ionization Mass Spectrometry

6. *In silico* insights into the molecular mechanisms governing therapeutic properties

Molecular docking and systems-level analyses indicate that *J. sambac* exerts its therapeutic effects through multi-target modulation of intracellular signalling pathways mediated by bioactive flavonoids, phenolics, terpenoids, and volatile constituents. *In silico* studies have consistently identified the phosphoinositide 3-kinase-protein kinase B-mammalian target of rapamycin (PI3K-AKT-mTOR) axis as a key molecular target, particularly in cancer (Abd Emoniem *et al.,* 2023). Major constituents such as coumarin derivatives, quercetin, hesperidin, benzyl acetate, and linalool exhibit strong binding affinities toward PI3K, AKT, and mTOR, suggesting suppression of kinase-driven survival signalling, inhibition of aberrant cell proliferation, and induction of apoptosis (Al Hassan *et al*., 2025; Singh and Meena, 2022; Lakshmi *et al*., 2024; Marappan *et al.,* 2025). Network pharmacology further reveals interactions with multiple oncogenic and inflammatory regulators, including epidermal growth factor receptor (EGFR), MAPK, CASP3, and NF-κB associated proteins, supporting coordinated regulation of cell cycle progression, apoptotic pathways, and inflammatory responses (Jamal *et al.,* 2025). Concurrent activation of the nuclear factor erythroid 2-related factor 2-heme oxygenase-1 (Nrf2-HO-1) pathway enhances antioxidant defenses and redox homeostasis, contributing to cytoprotective effects (Liu *et al*., 2023). Beyond oncology, integrative network and docking approaches implicate *J. sambac* bioactive compounds in metabolic and inflammatory regulation through interactions with glucagon receptor (GCGR), glycogen synthase kinase 3 beta (GSK3B), and peroxisome proliferator-activated receptors alpha and gamma (PPARA and PPARG), linking these targets to lipid metabolism, glucose homeostasis, oxidative stress control, and inflammatory cascades (Alghifari and Jamil, 2023). Additionally, LC-MS/MS guided metabolite profiling coupled with molecular docking has identified several phytoconstituents such as linalyl benzoate and benzene methanol with high predicted affinity toward diabetes-associated targets, including glucose transporter type 4 (GLUT4), α-glucosidase, and human glucokinase, highlighting a plausible molecular basis for the antidiabetic activity of *J. sambac* (Alghifari and Jamil, 2023; Bohari *et al*., 2025). These *in silico* findings provide a rational framework for drug discovery by prioritizing lead phytochemicals, predicting multi-target efficacy, and guiding structure-based optimization and experimental validation towards the development of novel, plant derived therapeutics.

7. Drug development and nanoformulation strategies

While the bioactive constituents of *J. sambac*, exhibit versatile therapeutic properties, their clinical translation is limited by poor aqueous solubility, low bioavailability, chemical instability, and lack of target specificity. Recent advances in nanotechnology-based delivery systems provide effective strategies to overcome these constraints and enhance therapeutic performance. Plant-mediated (green) synthesis of metal nanoparticles using *J. sambac* extracts has emerged as a sustainable nanofabrication approach. Zinc oxide nanoparticles (ZnO-NPs) synthesized using leaf extracts act as both reducing and capping agents, yielding spherical, crystalline nanoparticles ($\approx$ 25-60 nm) stabilized by phytochemicals. These phyto-fabricated ZnO-NPs demonstrate broad spectrum antibacterial activity against *S. aureus* and *E. coli*, along with antiinflammatory, antipyretic, and antispasmodic effects in functional assays. Importantly, anticancer studies reveal dose-dependent cytotoxicity

against human cancer cell lines (A549 lung carcinoma), mediated through increased reactive oxygen species (ROS) generation, mitochondrial dysfunction, DNA damage, upregulation of pro-apoptotic genes (*Bax, p53*), downregulation of B-cell lymphoma-2 (*Bcl-2*), and activation of caspase-3 (CASP3) dependent apoptosis, while maintaining biocompatibility with normal fibroblast cells (Sugitha *et al*., 2024; Raveendran *et al*., 2025).

In parallel, nano emulsion-based delivery systems have been developed to enhance the stability and bioavailability of jasmine essential oils. Oil-in-water nano emulsions formulated using non-ionic surfactants achieved nanoscale droplet sizes (~70 nm), low polydispersity index, and improved physicochemical stability. These formulations preserved the antioxidant activity of major volatile constituents such as benzyl acetate and benzyl alcohol, as confirmed by DPPH radical scavenging and metal chelation assays. Functionally, nano emulsions inhibited enzymatic browning by suppressing phenylalanine ammonia lyase (PAL), polyphenol oxidase (PPO), and peroxidase (POD) activity, thereby maintaining petal colour, freshness, and cellular integrity during cold storage in *J. sambac*. Although primarily explored for postharvest applications, these systems demonstrate the broader potential of nano emulsification for improving delivery of hydrophobic phytochemicals (Yeamsuriyotai *et al*., 2025).

Mechanistically, nano-enabled *J. sambac* formulations enhance cellular uptake and bioactive stability, enabling more effective modulation of oncogenic signalling pathways such as PI3K–AKT and MAPK, while promoting apoptosis through caspase activation. Overall, the integration of *J. sambac* phytochemistry with nanomedicine offers a promising translational framework for developing safer, targeted, and multifunctional therapeutic platforms, particularly in anticancer, antimicrobial, and antiinflammatory drug development (Nomier *et al*., 2024).

8. Cytotoxicity and toxicological safety

The safety profile of *J. sambac* has been evaluated through a combination of preliminary toxicity screening assays, mammalian cell-based cytotoxicity studies, and *in vivo* toxicological investigations. Early stage assessment using the brine shrimp (*Artemia salina*) lethality bioassay demonstrated dose-dependent lethality of ethanolic extracts, indicating general bioactivity; however, this model provided only nonspecific toxicity information and does not directly reflect mammalian safety (Rahman *et al*., 2011). More biologically relevant *in vitro* studies have shown low cytotoxicity and haemolytic activity towards normal mammalian cells (Kunhachan *et al*., 2012; Wu *et al*., 2021; Lakshmi *et al*., 2024; Saleem *et al*., 2025). Extract mixtures tested on human skin fibroblasts (CCD-966SK) and human epidermal melanocytes (HEMn) maintained high cell viability (>80%) even at concentrations up to 4000 mg/l, supporting biocompatibility at physiologically active levels (Wu *et al*., 2021). Comparable outcomes have been reported for essential oil formulations and nano-enabled systems, where minimal toxicity was observed in normal cell lines using MTT assays, indicating selective bioactivity rather than generalized cytotoxicity (Sugitha *et al*., 2024).

In vivo toxicological evaluations further confirm a wide margin of safety. Acute oral toxicity studies conducted in rodents according to Organisation for Economic Co-operation and Development (OECD) guidelines (420 and related protocols) reported median lethal dose (LD_{50}) values exceeding 2000-5000 mg/kg body weight for leaf and flower extracts. No mortality, neurobehavioral abnormalities, or significant changes in body weight, organ weight, or gross pathology were observed. Biochemical analyses revealed stable liver and kidney function markers, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), creatinine, blood urea nitrogen (BUN), and serum glutamic oxaloacetic and pyruvic transaminases (SGOT/SGPT). Histopathological examinations also showed preservation of hepatic, renal, and cardiac tissue architecture, with no evidence of systemic toxicity (Kunhachan *et al*., 2012; Al-Rashdi *et al*., 2012; Veereshbabu *et al*., 2017; Jain, 2018). Advanced formulations, including nano emulsions and phyto-fabricated metal nanoparticles, did not introduce additional toxicological risks. Instead, these systems enhanced bioactive stability and efficacy while maintaining favourable biocompatibility profiles in both *in vitro* and *in vivo* models.

9. Future directions and challenges

Beyond its long-standing use in fragrance and ornamental landscaping, *J. sambac* has emerged as a multifunctional medicinal plant supported by substantial evidence from traditional practice and modern pharmacological investigations. Its therapeutic potential is underpinned by a diverse array of volatile and non-volatile secondary metabolites that exert bioactivity through multi-target and pathway-level mechanisms. Available preclinical data indicate favourable safety margins, good biocompatibility with normal mammalian cells, and low systemic toxicity, collectively supporting its promise for further pharmaceutical and cosmeceutical development.

Despite these encouraging attributes, several critical challenges must be addressed to enable clinical translation. A major limitation is the marked variability in extract composition resulting from differences in plant parts used, cultivation practices and environmental conditions, extraction methodologies, and the current lack of rigorous phytochemical standardization. Moreover, effective drug development is constrained by the low bioavailability of many *J. sambac*-derived phytochemicals, necessitating focused strategies to improve their pharmacokinetic performance. Most reported pharmacological activities are still largely supported by *in vitro* assays, animal models, or *in silico* predictions, with limited mechanistic validation using advanced molecular and cellular approaches and a notable absence of well-designed human clinical trials. While molecular docking and network pharmacology offer valuable mechanistic hypotheses, these predictions require robust experimental confirmation at the protein, pathway, and multi-omics levels.

Future research should therefore emphasize systematic extract standardization through the identification and validation of reliable chemical markers, alongside comprehensive pharmacokinetic and bioavailability studies to better define dose-exposure relationships. Rigorous long-term safety evaluations, including chronic toxicity, genotoxicity, and potential herb-drug interactions, are essential to support translational development. Well controlled clinical trials will be indispensable to establish therapeutic efficacy and safety in humans. In parallel, advanced nano formulation strategies, such as phyto-fabricated metal nanoparticles and nano emulsions represent promising avenues to enhance solubility, stability, and targeted delivery of *J. sambac* bioactive compounds; however, challenges related to long-term biosafety, regulatory acceptance, and scalable manufacturing must be carefully resolved before clinical and commercial applications.

10. Conclusion

The Arabian jasmine (*J. sambac*), long adorned for its ornamental appeal and economic importance in floriculture, is now increasingly recognized for its pharmacological versatility, offering a meaningful link between traditional folk use and modern biomedical research. Its broad spectrum of bioactive constituents, acting through multiple therapeutic targets, supports its potential as a promising candidate for future drug and cosmeceutical development. However, key challenges particularly, the lack of consistent phytochemical standardization, issues related to bioavailability, and the need for clearer validation of signalling pathways using advanced experimental models continue to limit its clinical translation. Much of the available evidence is still preclinical, which warrants the need for well-designed human studies to better establish its bioefficacy and safety. From a translational perspective, integrative strategies that combine standardized extract characterization, comprehensive pharmaco-kinetic profiling, long-term toxicity evaluation, and innovative nanoenabled delivery approaches will be critical to unlocking the full therapeutic value of *J. sambac* and to position it as a clinically relevant natural product.

Author contributions

SG-conceptualization, manuscript writing, reviewing and editing; SS-Data compilation and manuscript writing; Both authors SG and SS contributed equally; SPT, MG, RR and PB-manuscript review and editing

Conflict of interest

The authors declare no conflicts of interest relevant to this article

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